Rescattering effects and Calculation of the survival factor in pp scattering processes

XXXV International Symposioum on Multiparticle Dynamics

August 9-15, 2005

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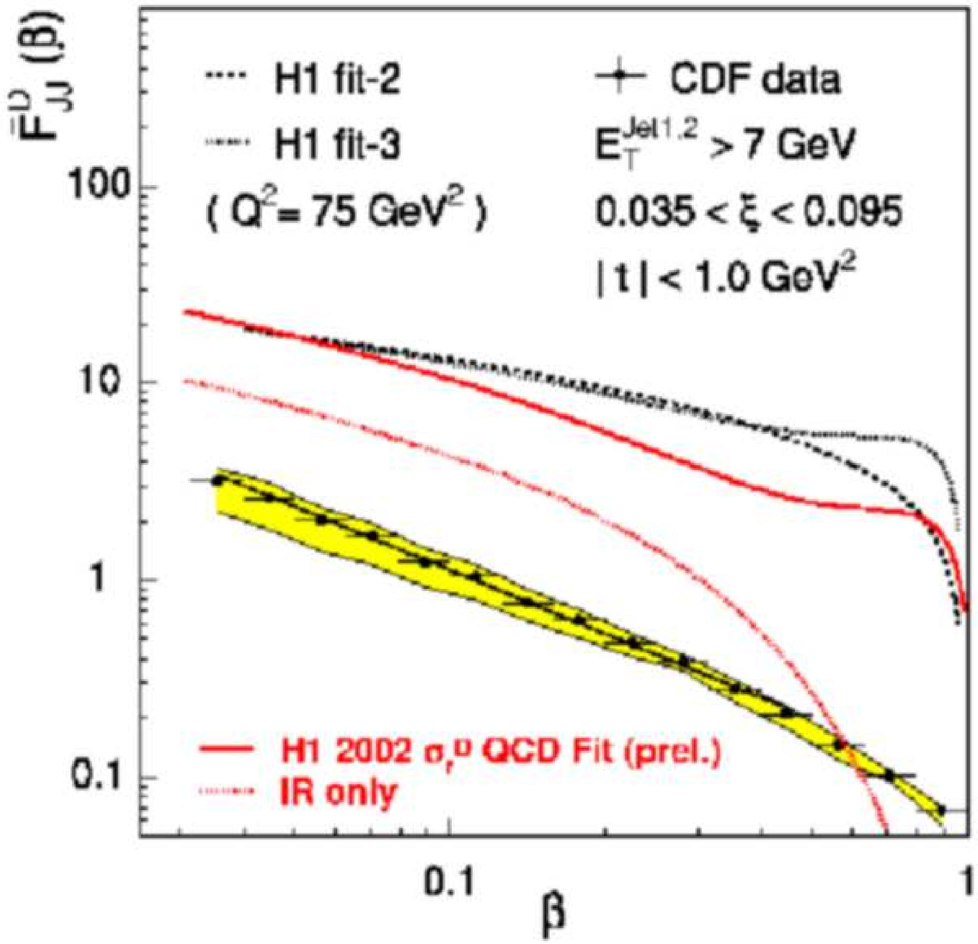
Hard diffraction - factorization breaking

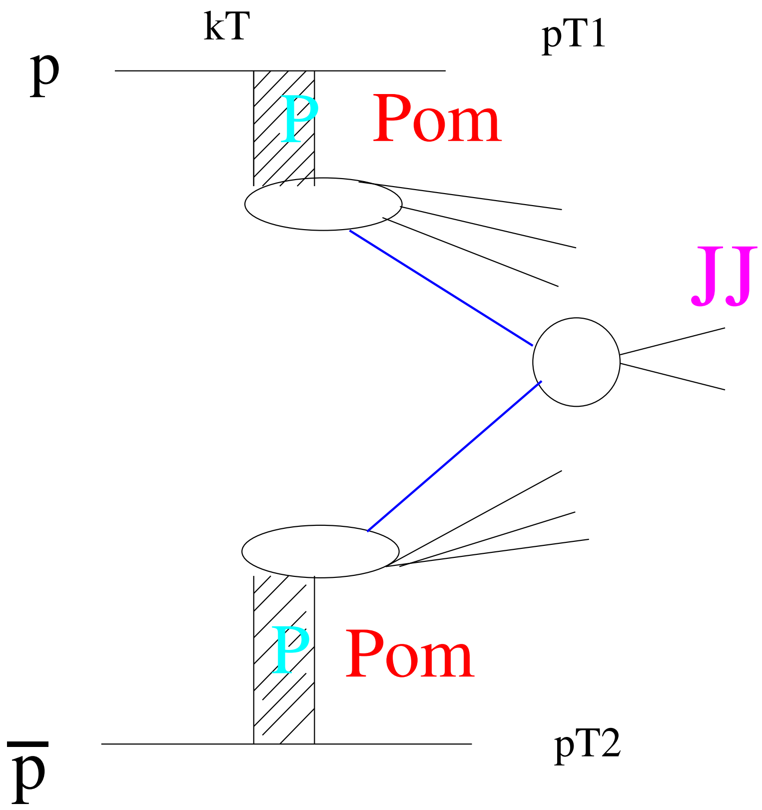


- Pomeron model:
  - diffraction - exchange of color-less objects - Pomerons
  - central interaction is then explained as a hard scattering of Pomeron constituents ⇒ Pomeron structure functions:

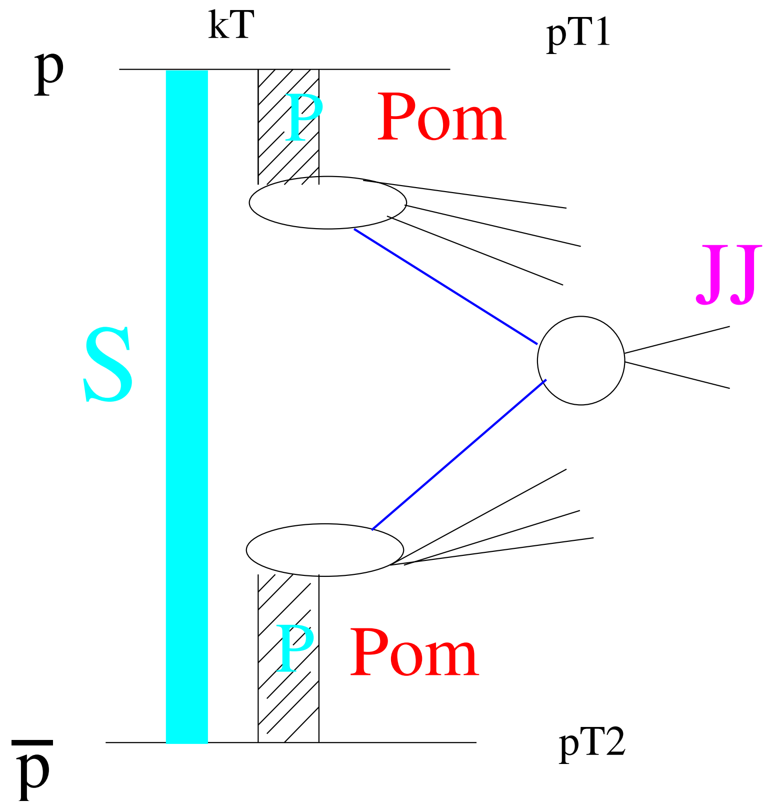
$$\sigma_{diff} \propto P_{(\mathbb{P}|p)}(x) \cdot F^D_{(A|\mathbb{P})}(\beta, Q^2) \cdot |\mathcal{M}|^2$$

Factorization breaking observed between Hera and Tevatron data

Survival probability



$\mathcal{A}_{hard}$



$\mathcal{A}_{rescat} = i\,\mathcal{A}_{el} \otimes \mathcal{A}_{hard}$

Survival probability

$$S^2 = \frac{\int |\mathcal{A}_{hard} + \mathcal{A}_{rescat}|^2}{\int |\mathcal{A}_{hard}|^2} = \frac{\int \mathrm{d}\vec{b} |\mathcal{A}_{hard}(s,b)|^2 \overbrace{|1 + i\mathcal{A}_{el}(s,b)|^2}^{\exp[-\Omega(b)]}}{\int \mathrm{d}\vec{b} |\mathcal{A}_{hard}(s,b)|^2}$$

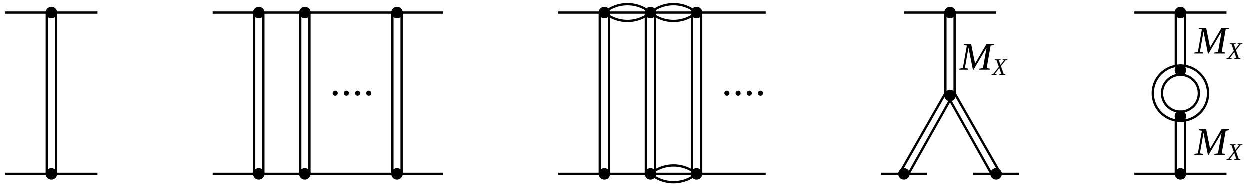
- hard amplitude $\mathcal{A}_{hard}$
  - factorization of the t-dependence at small $t(\equiv -p_T^2)$

$$\mathcal{A}_{hard}(\vec{p}_{T1}, \vec{p}_{T2}, \ldots) = \beta_{hard}(t_1)\beta_{hard}(t_2)A_0(\sqrt{s}, y, M)$$

$\Rightarrow$ survival probability factor independent on the hard interaction

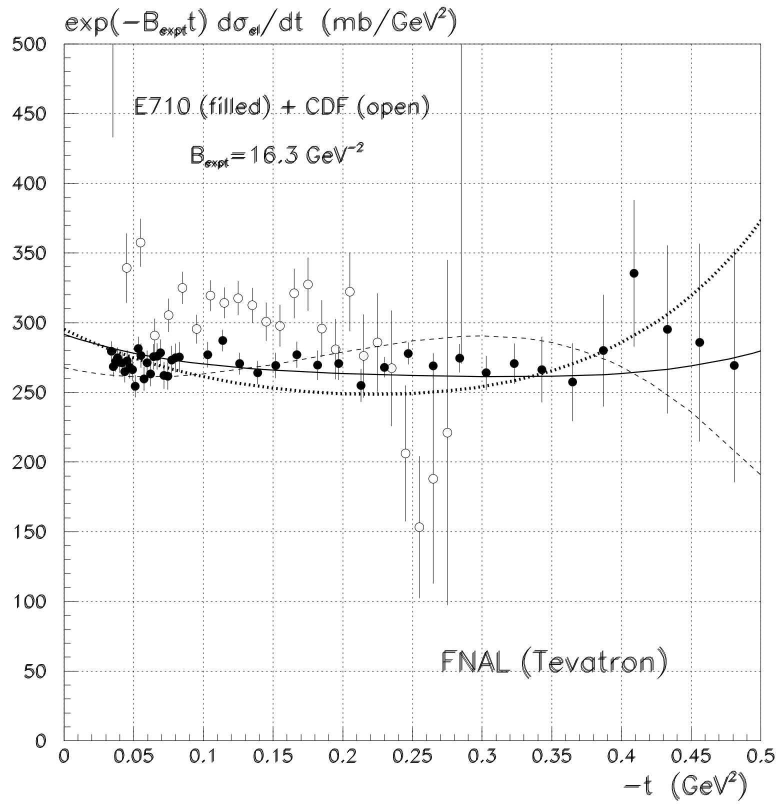
- Key ingrediencies:
  - models of elastic scattering amplitude $\mathcal{A}_{el}$
  - models of transverse distribution of nucleon constituents

Soft scattering in pomeron based model



Khoze, Martin, Ryskin
Eur. Phys. J. C18 (2000) 167

- extension to Donnachie-Landshoff: $\alpha_{\mathbb{P}}^{\text{eff}}(t) = 1.08 + 0.25t$
- adding 2-π loop corrections to pomeron trajectory
- retrieving s-channel unitarity
- 2-channel eikonal approach
- high-mass M_X single and double dissociation
- fitted on available σ_{tot} and $d\sigma_{el}/dt$ data
  - good description of data



Predictions for survival probability

$\sqrt{s}$ (TeV)	$2b$ (GeV^{-2})	Survival probability S^2 for: SD (FPS)	SD (cal)	CD (FPS)	CD (cal)	DD
0.54	4.0	0.14	0.13	0.07	0.06	0.20
	5.5	0.20	0.18	0.11	0.09	0.26
	7.58	0.27	0.25	0.16	0.14	0.34
1.8	4.0	0.10	0.09	0.05	0.04	0.15
	5.5	0.15	0.14	0.08	0.06	0.21
	8.47	0.24	0.23	0.14	0.12	0.32
14	4.0	0.06	0.05	0.02	0.02	0.10
	5.5	0.09	0.09	0.04	0.03	0.15
	10.07	0.21	0.20	0.11	0.09	0.29

$$|\mathcal{M}(b_t)|^2 \propto \exp(-b_t^2/nb)$$

$$n_{(CC,SD,DD)} = 4, 6, 8$$

for p + gap + H + gap + p

$$S^2 \approx 0.02 - 0.04$$

- updated number from Kaidalov et al., Eur. Phys. J. C33(2004) 261:

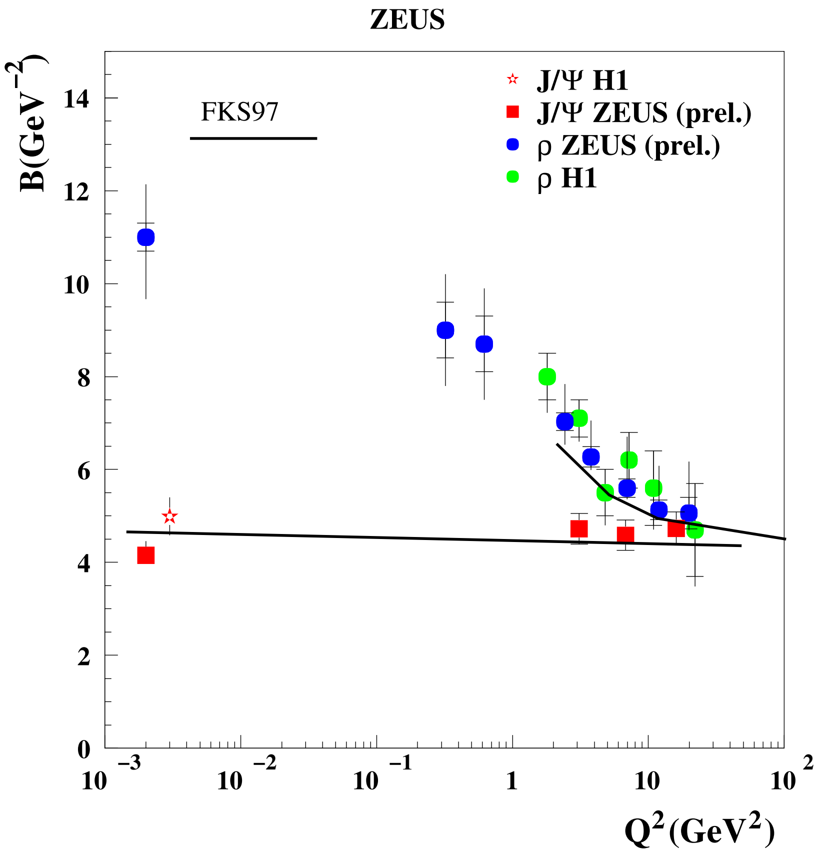
  $S^2 \approx 0.026$ with about $\pm 50\%$ uncertainty

- Petrov, Ryutin: 3 pomerons fit, $S^2 \approx 0.07$ (JHEP 0408:013, 2004)

Transverse structure of proton at large $\sqrt{s}$

Frankfurt, Strikman, Weiss, Zhalov

hep-ph/0412260

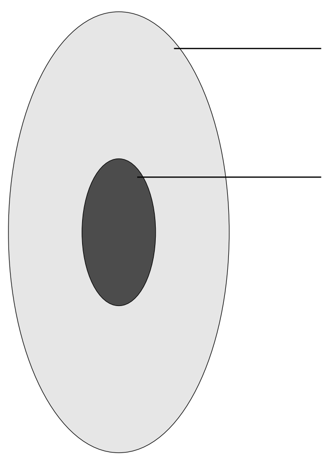


- probed in hard exclusive photo-production processes

$$\frac{d\sigma^{\gamma^\star p \to J/\Psi p}}{dt} \propto \left[F_g(x,t)\right]^2 , \; x \sim M_{c\bar{c}}^2 / W^2$$

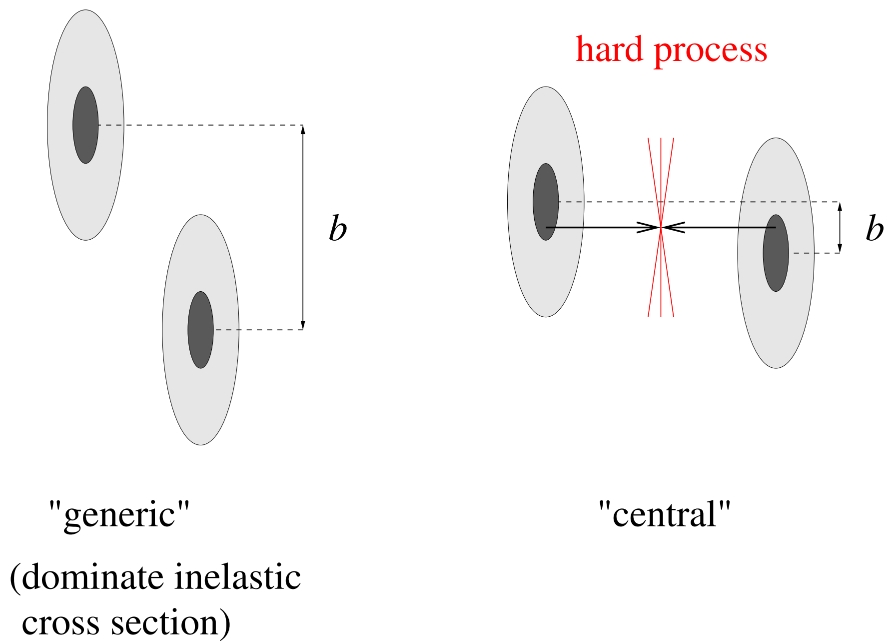
$F_g(x,t)$ ... two-gluon form factor

$$F_g(x,b) = \int \frac{d^2\vec{k}_t}{(2\pi)^2} F_g(x, t \equiv -k_t^2) e^{-i\vec{k}_t \cdot \vec{b}}$$



$$F_g(x,t) = (1 - t/m_g^2)^{-2}$$

Centrality of hard interactions

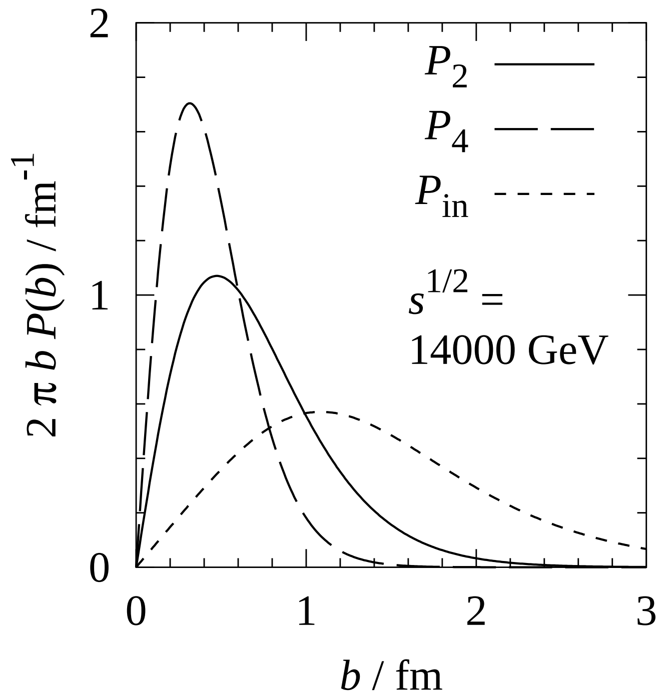


- hard dijet production

$$P_2(b) = \int \mathsf{d}\vec{b}_1 \mathsf{d}\vec{b}_2\, \delta(\vec{b}-\vec{b}_1-\vec{b}_2)\, F_g(b_1) F_g(b_2)$$

- 2 binary hard dijet productions

$$P_4(b) = \frac{[P_2(b)]^2}{\int \mathsf{d}\vec{b}'\, [P_2(b)]^2}$$

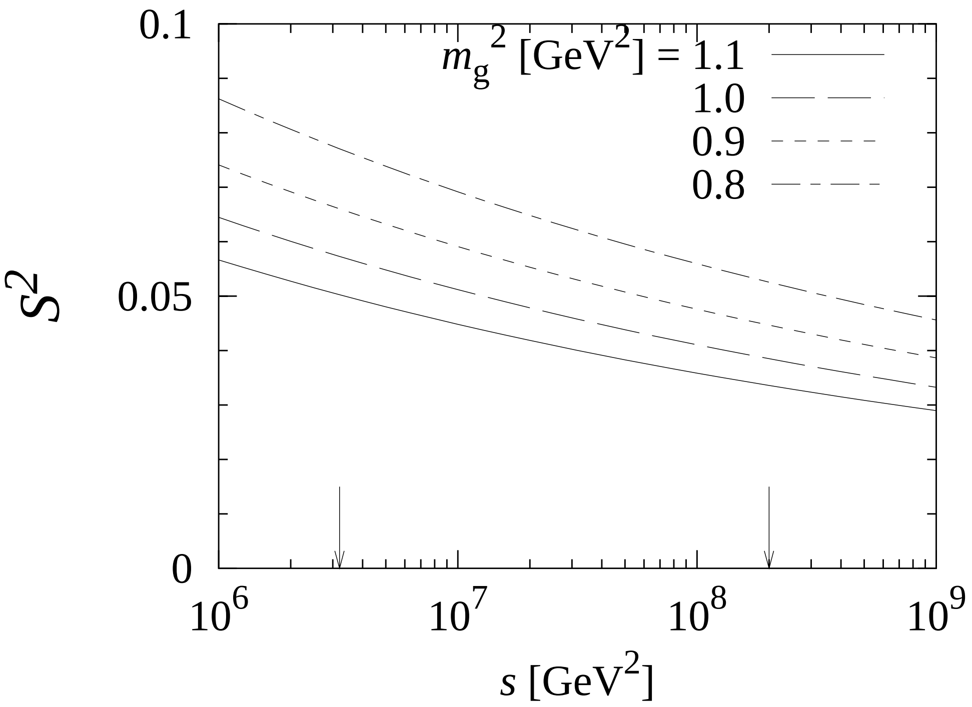


- inelastic events

$$P_{in}(s,b) = \frac{2\,\mathsf{Im}\mathcal{A}_{el}(s,b) - |\mathcal{A}_{el}(s,b)|^2}{\sigma_{in}(s)}$$

- $\mathcal{A}_{el}(s,b)$ from Islam et al.
  Mod. Phys. Lett. A18 (2003) 743

Gap Survival at LHC



$\mathsf{p} + \mathsf{p} \to \mathsf{p} + \mathsf{gap} + \mathsf{H} + \mathsf{gap} + \mathsf{p}$

- need to exchange 2 hard gluons:

$$S^2 = \int \mathrm{d}\vec{b}\, \underbrace{|1 + i\mathcal{A}_{el}|^2}_{\exp[-\Omega]} P_4(b)$$

- effective values of m_g^2 decreases with decreasing x

$\Rightarrow$ drop is actually smaller than for fixed value of m_g^2

- results in reasonable agreement with KMR

Factorization breaking - Good-Walker picture

Bialas, Acta Phys. Polon. B33 (2002) 2635

- diffractive dissociation treated as a consequence of absorption of the particle waves

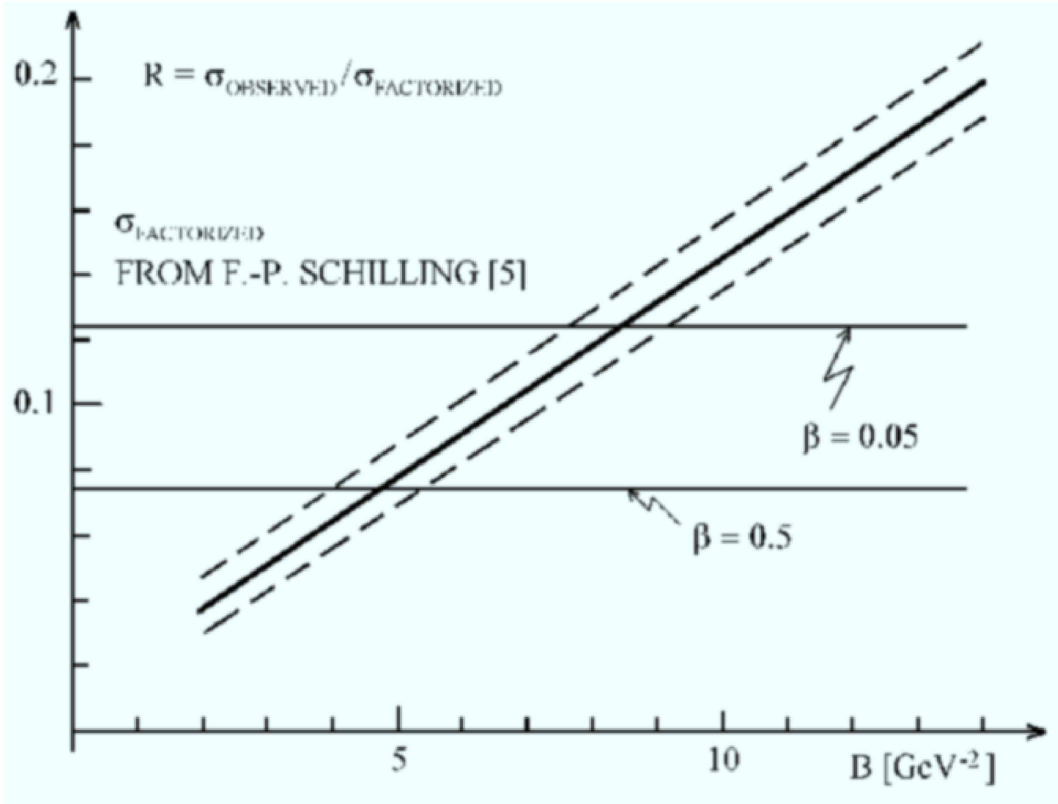
$$\langle \text{jets}|T|\gamma^\star\rangle = \epsilon \langle \text{hard}|T|\text{hard}\rangle$$

$$\Big\langle P' + \text{jets}|T|P\Big\rangle = \epsilon \langle \text{hard}|T|\text{hard}\rangle \left(1 - \langle P|T|P\rangle\right)$$

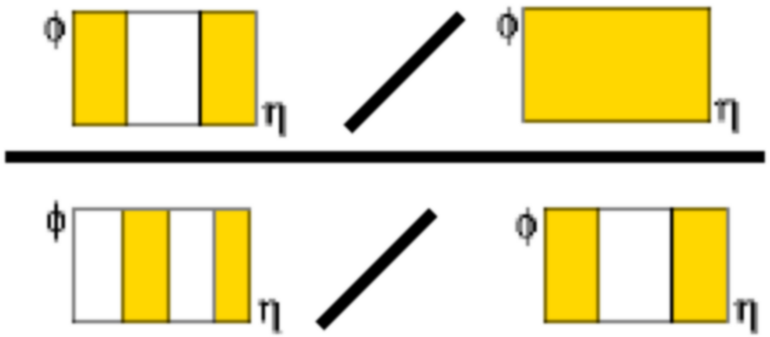
- suppression factor:

$$|1 - \langle P|T|P\rangle|^2$$

- using Donnachie-Landshoff parametrization of the elastic amplitude



Dijets at Tevatron with 0, 1, and 2 rapidity gaps



$R_{exp} \approx 0.23\ (\pm 30\%)$

Bialas, Peschanski, Phys. Lett. B575 (2003) 30

$$R_{1|0}/R_{2|1} = R_{1|0}^2/R_{2|0} \approx 0.25$$

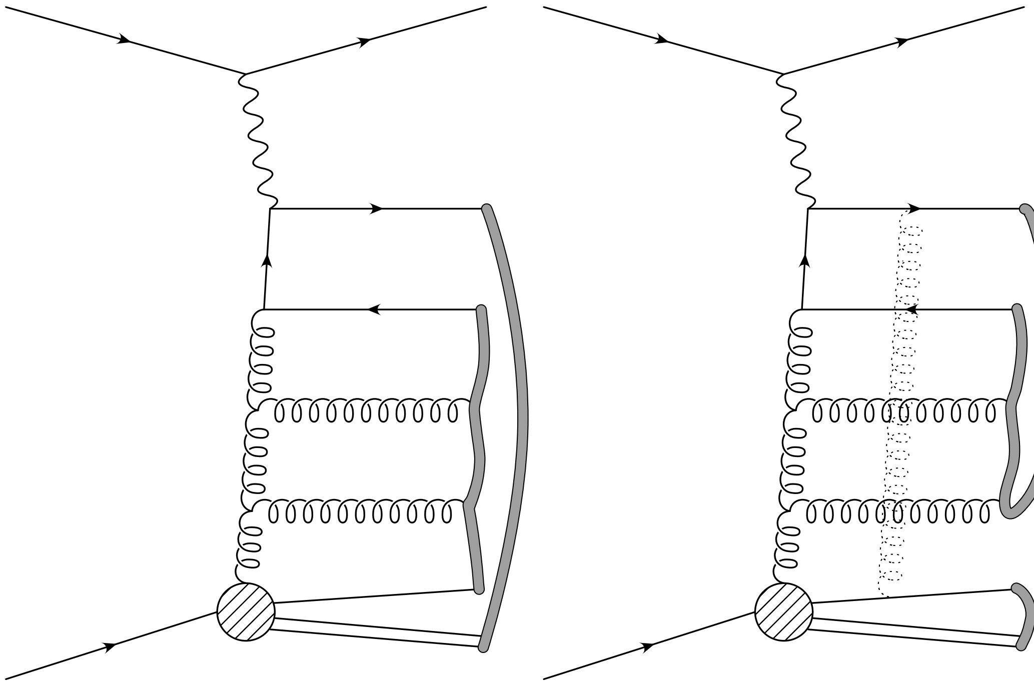
Kaidalov, Khoze, Martin, Ryskin
Phys. Lett. B559 (2003) 235

- same formula
- $R_{1|0}/R_{2|1} \approx 0.2$

similar to other predictions by

- Goulianos
- Gotsman-Levin-Maor
- Soft color interactions model

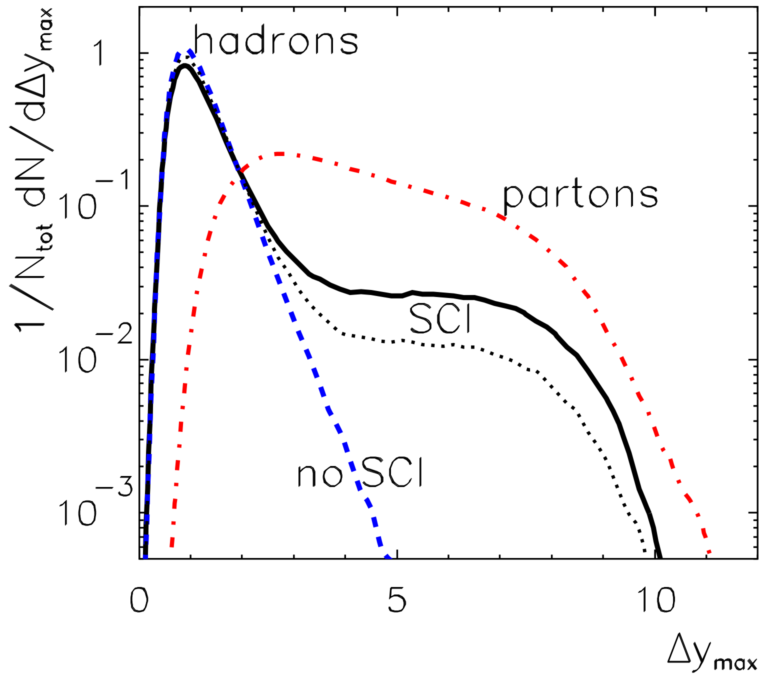
Soft color interactions (SCI)



Enberg, Ingelman, Timneanu, Phys. Rev. **D64** (2001) 114015

Brodsky, Enberg, Hoyer, Ingelman, Phys. Rev. **D71** (2005) 074020

- based on Lund string model



- after development of partonic shower, additional soft color interaction can occur between partons with probability P
- from fits of F_D^2 data

$$P \approx 0.5$$

SCI - Tevatron and LHC predictions

Process	Experiment		Ratio [%]	
			Observed	SCI
W	CDF	[13]	1.15 ± 0.55	1.2
Z	DØ	[14]	$1.44^{+0.62}_{-0.54}$	$1.0^\dagger$
$b\bar{b}$	CDF	[35]	0.62 ± 0.25	0.7
J/ψ	CDF	[36]	1.45 ± 0.25	$1.4^\dagger$
dijets	CDF	[10]	0.75 ± 0.10	0.7
dijets	DØ	[12]	0.65 ± 0.04	0.7

† Predictions made in advance of the data.

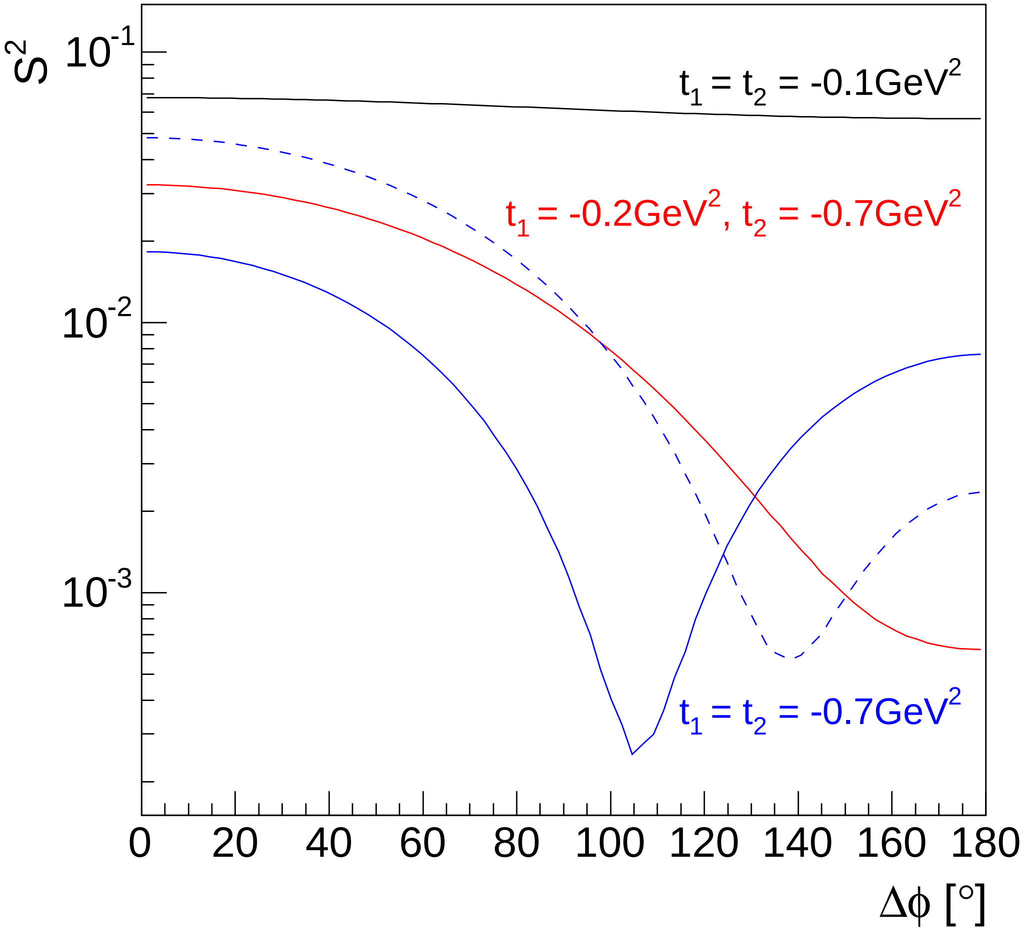
- Unified description of diffractive and non-diffractive final states

$\Rightarrow$ no survival factors

- very good desciption of available diffractive data from Hera and Tevatron

- at LHC, gives orders of magnitude lower σ for exclusive Higgs production
  - leading protons with $x_F > 0.9$: $\sigma \sim 0.19$ fb
  - requiring gaps: $\sigma \sim 3 \times 10^{-4}$ fb (KMR: 2 fb)
- in SCI model, it is extremely unlikely to create exclusive state

Survival probability - $\Delta\phi_{p\bar{p}}$ dependence



- rich structure in $\Delta\phi$

  V. A. Khoze, A. D. Martin and M. Ryskin, Eur. Phys. J. **C24** (2002) 581

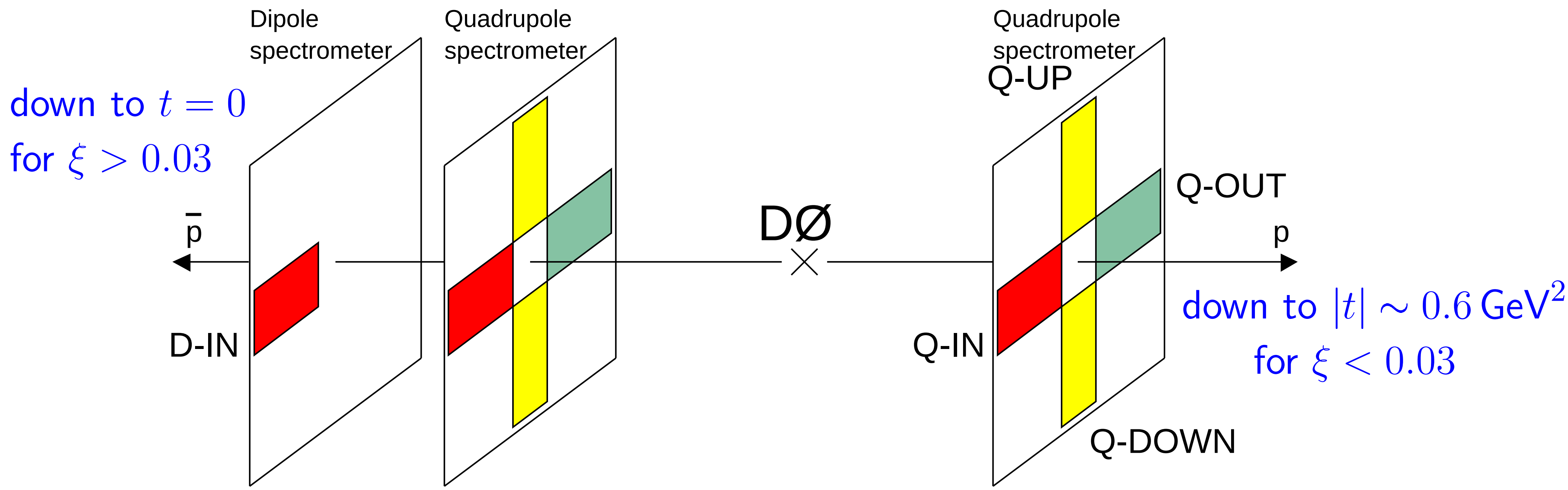
- the same origin as the diffractive dips in $d\sigma_{el}/dt$
- the position of the dip is sensitive to the details of the model
- This is a general feature of all pomeron based models

There is no $\Delta\Phi$ dependence in SCI model

DØ Forward Proton Detector

Kupčo, Peschanski, Royon, Phys. Lett. B606 (2005) 139

- Forward Proton Detector installed by DØ provides an unique opportunity to measure the $\Delta\phi$ dependence of the hard diffractive production



Dipole-Quadrupole combination

D-IN & Q-IN, D-IN & Q-OUT

D-IN & Q-UP or D-IN & Q-DOWN

- asymmetric cuts in t

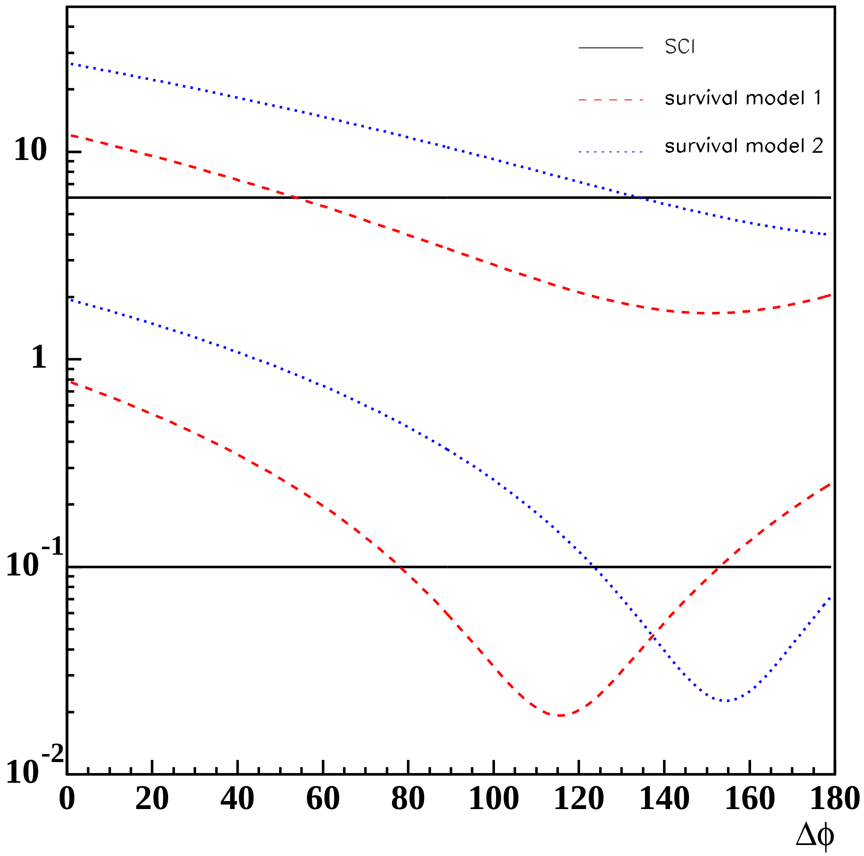
Quadrupole-Quadrupole combination

same side, opposite side

middle (90°) configuration

- symmetric cuts in t

Results for double diffractive dijet production



- dijet production with $p_T > 5$ GeV at Tevatron
  - upper plots: $|t_p| > 0.6,\ |t_{\bar{p}}| > 0.1$ GeV^2
  - lower plots: $|t_p| > 0.5,\ |t_{\bar{p}}| > 0.5$ GeV^2
- Pomeron models
  - POMWIG interfaced with the calculation of survival probability

After simulation of FPD acceptance:

Config.	model	$N_{90}/2 \times N_{SS}$	N_{OS}/N_{SS}
Quad.	SCI	1.3	1.1
+	P-Model 1	0.36	0.18
Dip.	P-Model 2	0.47	0.20
Quad.	SCI	1.4	1.2
+	P-Model 1	0.14	0.31
Quad.	P-Model 2	0.20	0.049

Summary

- Various approaches to the explanation of the factorization breaking in diffractive events between Hera and Tevatron give good description of available data.
- This is not surprising, since the formulas for survival factors are similar.
- Discrepancies are at LHC larger, but still not far away:

$$S^2_{p+H+p} \sim 0.02 - 0.05$$

- The only exception is Soft Color Interaction model, which gives orders of magnitude lower cross section in case of central exclusive production
- Azimuthal correlations of scattered protons in hard DPE are sensitive to the gap production mechanism and can be used to distinguish different models of factorization breaking.
- We showed, that DØ FPD is suitable for such measurement.